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Ministry of Economic Development
Manatū Ōhanga
Intellectual Property Office of New Zealand

PCT/NZ2005/000011

CERTIFICATE

This certificate is issued in support of an application for Patent registration in a country outside New Zealand pursuant to the Patents Act 1953 and the Regulations thereunder.

I hereby certify that annexed is a true copy of the Provisional Specification as filed on 23 February 2004 with an application for Letters Patent number 531314 made by SHUTTLEWORTH AXIAL MOTOR COMPANY LIMITED.

Dated 3 March 2005.

Neville Harris

Neville Harris
Commissioner of Patents, Trade Marks and Designs

COMMISSIONER OF PATENTS, TRADEMARKS & DESIGNS
NEW ZEALAND

330 High Street, Lower Hutt and 17 Toop Street, Seaview
PO Box 30687, Lower Hutt, New Zealand or DX SX 11129, Wellington
Phone: +64 4 560 1600, Fax: +64 4 560 1691, www.iponz.govt.nz

531314

NEW ZEALAND

PATENTS ACT, 1953

PROVISIONAL SPECIFICATION

RECIRCULATION SYSTEM FOR MOTOR

We, SHUTTLEWORTH AXIAL MOTOR COMPANY, a New Zealand company, of 110 Marsden Valley Road, Nelson, New Zealand, do hereby declare this invention to be described in the following statement:

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RECIRCULATION SYSTEM FOR MOTOR

FIELD OF THE INVENTION

The present invention relates to a recirculation system for a motor or engine and to a motor or engine incorporating the recirculation system. While the invention has application for axial motors, it also has applications for other motors. The term "motor" is used interchangeably with "engine".

BACKGROUND TO THE INVENTION

Over the years engine manufacturers have been working to improve the weight, size efficiency and manufacturing costs of engines. In part this has lead to the development of axial motors. An axial motor includes an engine block in which the cylinders are spaced evenly in a circular configuration about an axis of the engine block, rather than in the inline, "V" or horizontally opposed configurations of traditional engines. The reciprocal motion of the pistons in an axial motor can be transferred to rotational motion of an output shaft by way of a wobble plate configuration, such as that disclosed in NZ 221336.

Generally, as with conventional internal combustion engines, the compression ratio and therefore power output of the axial motor is at least in part limited by the quality of the fuel being burnt. If poor quality fuel is used, a lower compression ratio must be used in the motor or else "knocking" or auto-igniting will occur, which ultimately could damage components of the motor. Some high density fuels such as diesel hydrocarbon fuel exhibit poor combustion properties as they are difficult to atomise prior to combustion.

Systems which deliver exhaust gas to cylinders to go some way towards improving combustion properties and/or reducing emissions are described in US 6,427,644; US 5,782,226; US 4,475,524 and EP 0682743.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a recirculation system for a motor which is operable to improve combustion properties and improve performance and/or which at least provides the public with a useful choice.

In a first aspect, the invention may be said to broadly consist in a motor including an engine block with a plurality of cylinders arranged to fire with a firing order, and including a recirculation system configured to deliver combusted mixture under combustion pressure and temperature from a cylinder which has just fired to at least partly mix with fuel for the next cylinder in the firing order to improve the combustion properties of the fuel.

It should be noted that where reference herein is made to "combusted mixture under combustion temperature and pressure", that need not mean that the temperature and pressure will be at the same levels as at the time of combustion, as pressure and temperature losses will occur during transfer of the mixture. However, the mixture will be at a significantly elevated temperature and pressure relative to the combustible mixture in the next cylinder in the firing order.

In one embodiment, each cylinder has an injector body associated therewith, each injector body having an internal chamber in communication with a fuel inlet port for delivering fuel into the internal chamber, a fuel outlet port for delivering fuel under pressure from the chamber into the associated cylinder, a mixture inlet port and a mixture outlet port, with the mixture inlet port of each injector body in fluid communication with the mixture outlet port of an adjacent injector body, the motor configured to deliver combusted mixture under combustion pressure and temperature from an outlet port of an injector body associated with a cylinder that has just fired to an inlet port of an injector body associated with the next cylinder in the firing order of the motor to at least partly mix with fuel in the internal chamber of that adjacent injector to improve the combustion properties of the fuel.

The fuel inlet port of each injector body is preferably configured for receipt of a respective fuel injector.

Transfer means are preferably provided to link the mixture outlet port of each injector body with the mixture inlet port of the injector body associated with the next cylinder in the firing order. The transfer means may be pipes, tubes, or the like.

In an alternative embodiment, the recirculation may occur internally within a cylinder head of the engine. Preferably, a pre-mix chamber is associated with each cylinder, and the motor includes transfer means configured to deliver combusted mixture under combustion temperature and pressure from the pre-mix chamber associated with a cylinder that has

just fired to the pre-mix chamber associated with the next cylinder in the firing order. It is preferred that a fluid path is provided between each pre-mix chamber and the respective cylinder, and preferably the fluid path includes a nozzle which may include a restriction to deliver mixture for combustion into the respective cylinder under pressure.

The motor may be an inline, "V", or horizontally opposed ("boxer") configuration two- or four-stroke internal combustion motor. Alternatively, the motor may be a two- or four-stroke axial motor. The system could also be used with a rotary engine.

In the two-stroke embodiment, the motor is preferably configured such that the combusted mixture is delivered to at least partly mix with the fuel for the next cylinder in the firing order as the piston in that next cylinder is nearing the top of its compression stroke. Preferably, when a cylinder is on its compression stroke, some air/fuel mixture is delivered under relatively low pressure to the next cylinder in the firing order as that next cylinder is undertaking its compression stroke.

Preferably, combusted mixture is delivered between injector bodies or parts of the cylinder head in a sequential manner, the sequence corresponding to the firing order of the motor.

In a second aspect, the invention may be said to broadly consist in a recirculation system for a motor which includes a plurality of fuel injector bodies, each injector body having an internal chamber in communication with a fuel inlet port for delivering fuel into the internal chamber, a fuel outlet port for delivering fuel under pressure into an associated cylinder, a mixture inlet port and a mixture outlet port, and arranged with the mixture inlet port of each injector body in fluid communication with the mixture outlet port of an adjacent injector body, the recirculation system configured to deliver combusted mixture under combustion pressure and temperature from an outlet port of an injector body associated with a cylinder that has just fired to an inlet port of the injector body associated with the next cylinder in the firing order to at least partly mix with fuel in the internal chamber of that next injector body to improve the combustion properties of the fuel.

The fuel inlet port of each injector body is preferably configured for receipt of a respective fuel injector.

Preferably, each mixture inlet port includes a non-return valve which allows the mixture to travel into the chamber through the port but not out of the chamber through the port.

Preferably, each mixture outlet port includes a non-return valve which allows mixture to travel out of the chamber through the port but not into the chamber through the port. The fuel inlet port preferably includes a non-return valve which allows fuel to flow into the chamber through the fuel inlet port, but not out of the chamber through the fuel inlet port.

The mixture outlet port of each injector body is preferably connected to the mixture inlet port of an adjacent injector by a transfer means, which may be a pipe, tube, or the like.

Preferably, the combusted mixture at least partly atomises the fuel in the internal chamber.

In a third aspect, the invention may be said to broadly consist in a method of enhancing combustion in a motor having an engine block with a plurality of cylinders arranged to fire with a firing order, including delivering combusted mixture under combustion pressure and temperature from a cylinder which has just fired to at least partly mix with fuel for the next cylinder in the firing order to improve the combustion properties of the fuel.

The motor may have one or more of the features outlined in respect of the first and second aspects above.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the invention will be described with reference to the accompanying drawings in which:

Figure 1 is a plan view of an engine block of an axial motor which may be used with the recirculation system of the present invention;

Figure 2 is a part diagrammatical plan view of the engine block from the opposite end of Figure 1 with an air chest cover removed, showing a radial compressor;

Figure 3 is a section through a multi-cylinder axial engine block showing the turbocharger and one cylinder and part of the recirculation system of the present invention, on a view through line A-A of Figure 1;

Figure 4 is a plan view of the recirculation system in accordance with a preferred embodiment of the present invention;

Figure 5 is a section through an injector body along line B-B of Figure 4; and

Figure 6 is a schematic diagram showing the sequence of operation of the fuel recirculation system of the present invention between three cylinders.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figures 1 to 3 show an axial two-stroke motor which may be used with the recirculation system of the present invention. The general motor arrangement and operation will be described first.

Figure 1 shows a top plan view of the axial two-stroke motor which includes an integral turbocharger. The axial two-stroke motor or engine 100 includes an engine block 106 preferably formed as an aluminium casting into which have been machined a plurality of cylinders 101-105. The cylinders are arranged in a substantially circular arrangement about a longitudinal axis 305 of the engine block 106 such that the cylinders are spaced substantially evenly about the axis 305. The longitudinal axis 305 is illustrated in Figure 3. In the preferred embodiment there are five cylinders 101-105 in the motor. More or less cylinders could be provided as is desirable.

The axial-two stroke motor 100 shown includes a turbocharger 308 which is disposed substantially within the engine block 106. Preferably the turbocharger 308 is aligned with the axis 305 of the engine block 106 such that it is surrounded by the evenly spaced cylinders 101-105.

Figure 1 shows an end view of the turbocharger 308 in which an exhaust turbine 107 which forms part of the turbocharger is visible. This illustrates that the location of the turbocharger 308 which is disposed in the engine block 106, is substantially within the centre of the circularly arranged cylinders 101-105. The location of the entire turbocharger 308 is more clearly illustrated in Figure 3. Each cylinder 101-105 has a respective opening 111-115 for an injector body of the recirculation system of the present invention to be described below. Apertures 111a-115a are provided for spark plugs or other ignition related devices. The block also includes tie down bolt holes 116-120.

Figure 2 shows the bottom plan view of the axial two-stroke engine 100. An air chest cover 320 has been removed to reveal a compression turbine 200 which forms part of the opposite end of the turbocharger 308. Formed between the compression turbine 200 and circularly arranged cylinders 101-105 is an air chest 201. The air chest 201 is linked to each cylinder 101-105 by way of transfer passages 202-206. Reed valves 207- 211 which are disposed between each transfer passage 202-206 and the air chest 201, control the air

flow between the air chest 201 and each transfer passage 202-206 . The operation of the air chest 201, reed valves 207-211 and transfer passages 202-206 will be described in detail below.

The integral turbocharger 308 arrangement will now be described in more detail with reference to Figure 3. Figure 3 shows a section view of an engine block 106 with five evenly spaced cylinders 101-105 about an axis 305 of the engine block 106. The section has been taken through A-A shown in Figure 1 and illustrates one 101 of the five cylinders 101-105.

Each cylinder 101-105 is substantially identical and therefore the description will refer to the visible cylinder 101 however it will be appreciated that the description will extend to all the cylinders 101-105 contained within the engine block 106. A piston 300 operates in a reciprocal motion within the cylinder 101 . The cylinder 101 has associated with it an injector body 401 which forms part of one preferred recirculation system of the present invention.

Associated with the piston 300 is a connecting rod 302. A ball joint 303 disposed at one end of the connecting rod 302 is located in an associated socket 304 disposed in a bottom portion of the piston 300. The reciprocal motion of the piston 300 and connecting rod 302 arrangement in the engine block 106 is transferred to rotational motion of an output shaft by any power transmission means suitable for an axial motor, for example a wobble plate arrangement.

Within the engine block there is a chamber aligned substantially axially with the longitudinal axis 305 of the engine block 106. The chamber forms an intake duct 306 and an exhaust collector duct 307. The turbocharger 308 is located within the chamber. The turbocharger 308 is located within the engine block 106 substantially in alignment with the axis 305 so that it is substantially parallel with the length of the cylinders 101-105. The turbocharger 308 includes a sub-assembly 309 which supports a rotatable turbine shaft 310, on one end of which is disposed the exhaust turbine 107 and on an opposite end is disposed the compression turbine or radial compressor 200.

Other features of the turbocharger are described in our PCT Publication No. WO 00/11330, the subject matter of which is incorporated herein by reference.

Disposed in the wall of the cylinder 101 are one or more exhaust ports 316 which are linked to the exhaust duct 307 via an exhaust passage 317. Also disposed in the wall of the cylinder 101 are one or more inlet ports 319 which are linked to the air chest 201 via the transfer passage 202 as shown in Figure 2. Reed valves 207 disposed between the transfer passage 202 and inlets to the air chest 201 control the flow of air between the air chest 201 and the transfer passage 202. The air chest 201 has an air chest cover 320. A diffusor 321 is formed between the air chest cover 320 and turbocharger sub-assembly 309.

Operation of the engine will now be described with reference to cylinder 101, however it will be appreciated that each cylinder is substantially identical and therefore any description with regard to the cylinder 101 should be considered to extend to the remaining cylinders.

The turbocharger is driven by exhaust gases 327 which are expelled from the cylinder 101. During the exhaust phase of the engine cycle, the piston 300 travels downwards within the cylinder 101 and exposes one or more exhaust ports 316 disposed in the cylinder 101 wall. The exhaust gases 327 from the combustion cycle are expelled from cylinder 101 through the one or more exhaust ports 316. The exhaust gases 327 pass through the exhaust passage 317, where the exhaust gases 327 pass through the stator 313 which guides the exhaust gases 327 directly onto the exhaust turbine 107. Once the exhaust gases 327 have impacted on the exhaust turbine 107 they pass through to the exhaust duct 307.

The rotation of the exhaust turbine 107 rotates the turbine shaft 310 and thus drives the compression turbine 200. The rotating compression turbine 200 draws air 328 through the intake duct 306 and passes the compressed air 328 through the diffusor 321 into the air chest 201. As the piston 300 rises the differential pressure opens the reed valves 207 and enables the air 328 from the air chest 201 to transfer to the volume 326 underneath the piston 300. During the air transfer portion of the combustion cycle, the piston 300 travels downwards within the cylinder 101 which pressurises the air 328 underneath the piston, thus closing the reed valves 207. As the piston 300 travels further the inlet ports 319 disposed in the wall of the cylinder 101 are exposed. The compressed air 328 in the volume 326 underneath the piston 300 is then transferred through the transfer passage 202-206 and the one or more inlet ports 319 into the cylinder 101.

In a further embodiment the engine includes a coolant jacket 322. The jacket 322 is formed by a combination of the turbocharger sub-assembly 309, inwardly protruding surfaces 314, 315 and engine block 106. The normal coolant used is water which can be fed into the coolant jacket 322 via a coolant entry port 323. The coolant circulates through the jacket 322 to enable heat dissipation from the turbocharger 308. The turbocharger sub-assembly 309 in combination with the mass of metal comprising the inwardly protruding surfaces 314, 315 and engine block 106 provides a sufficient heat sink to enable circulating coolant to dissipate heat from the turbocharger 308 upon cessation of the engine 100 operation. The dissipation of heat from the turbocharger 308 in this manner will minimise the likelihood of carbonisation of lubricant used within the turbocharger 308.

In a further embodiment a water cooling jacket may surround the external portion 400 of exhaust duct 307 to provide cooling for turbine shaft 310 and bearing 503.

The axial motor is configured with the preferred recirculation system of the present invention, with a layout shown more clearly in Figure 4. The preferred recirculation system is in the form of a fuel injection system which includes a plurality of injector bodies 401-405, each of which is mounted in an opening 111-115 associated with a respective cylinder 101-105. The injector bodies are configured to deliver gas to receive gas from the cylinders. A cross section through one of the injector bodies 401 is shown in Figure 5. While only one injector body is shown, it should be appreciated that the other injector bodies will have the same features. An upper part of the injector body 401 is configured for connection to a source of fuel, and more particularly includes an aperture 414 into which a fuel injector 416 such as shown in Figure 4 is inserted. Each of the fuel injectors 416 is connected to a tube or pipe 418 which will be in fluid communication with a fuel source and fuel pump (not shown). The fuel injectors 416 may be conventional electromagnetic solenoid valves.

The lower part of the injector body includes a fuel outlet port 428 and a nozzle 420 for delivering fuel into an associated cylinder. The nozzle 420 preferably includes a restriction orifice 422 to deliver fuel under pressure into the cylinder. The typical delivery pressure may be in the order of 90 psi (about 621 kPa). The aperture 414 and restriction orifice 422 are in fluid communication with an internal chamber 424 in the injector body via a fuel inlet port 426 and a fuel outlet port 428 respectively. A non-return valve 430 is provided in the fuel inlet port 426 to allow fuel to be delivered into the internal chamber

424 through the fuel inlet port 426 and to prevent fuel from travelling out through the fuel inlet port 426. The non-return valve 430 is preferably in the form of a ball valve.

The housing also includes a mixture inlet port 438 which extends into the housing and provides for the delivery of air/fuel mixture to the internal chamber 424. Again, the mixture inlet port includes a non-return valve 440 which may be of the type described above, and which allows mixture to travel into the internal chamber through the mixture inlet port but which also prevents mixture from exiting the housing from the internal chamber via the mixture inlet port.

A mixture outlet port 442 is also provided in the housing which allows mixture to travel out of the internal chamber 424. Again, the mixture outlet port includes a non-return valve 444 which may be of the type described above, and which allows mixture to travel out of the housing from the internal chamber, but which prevents mixture from travelling back into the internal chamber through the mixture outlet port. The fuel inlet port 426, fuel outlet port 428, mixture inlet port 438 and mixture outlet port 442 are all in fluid communication with the internal chamber 424. The mixture outlet port 442 is preferably of narrower diameter than the fuel outlet port 428, so there is greater resistance to fuel travel through the mixture outlet port 442 than through the fuel outlet port 428. In the preferred embodiment, the fuel outlet port and restriction orifice 422 are less restrictive than any other entry into or exit out of the injector body.

While the preferred internal chamber 424 is shown as a somewhat enlarged region within the injector body, that is not necessary and the chamber could instead simply be defined by a junction between the mixture inlet port, mixture outlet port, fuel inlet port and fuel outlet port.

Reverting to Figure 4, a transfer means which in the embodiment shown is a pipe, tube or the like 446 is connected between the mixture outlet port 442 of each injector body and the mixture inlet port of an injector body associated with the next cylinder in the firing order. More particularly, a connector 448 on one end of each pipe 446 is connected to the mixture inlet port of one of the injector bodies, and a connector 450 on the other end of each pipe 446 is connected to the mixture outlet port of the injector body associated with the next cylinder in the firing order. By this manner, the injector bodies are connected in a sequential manner around the engine block, which sequence corresponds to the firing order of the motor.

As will be described in more detail with reference to Figure 6, during operation of the motor combusted mixture is delivered under combustion temperature and pressure via the pipes 446, mixture outlet ports 442 and mixture inlet ports 438 to adjacent injector bodies associated with the following cylinders in the firing order, to improve combustion properties for the adjacent cylinders.

Figure 4 also shows an air-start valve 452 which is connectable to a source of air for starting the engine.

In Figure 6, three cylinders 101, 102, 105 of the engine are shown. As mentioned above, each cylinder has a respective fuel injector body 401, 402, 405 with a mixture inlet port 438 and mixture outlet port 442. The mixture outlet port 442 of each injector body is connected to the mixture inlet port 438 of a neighbouring injector body by a pipe 446. It will be appreciated that the mixture outlet port 442 of injector body 402 will be in fluid communication with the mixture inlet port 438 of injector body 403, and the mixture outlet port 442 of injector body 404 will be in fluid communication with the mixture inlet port 438 of injector body 405.

The motor is configured such that the cylinders fire sequentially around the motor. As this embodiment of axial motor has five cylinders, the pistons will be sequentially operating 72 degrees behind one another.

In the position shown in Figure 6a, the piston 300 in cylinder 101 is moving downwards towards bottom dead centre, and the injector body 401 is delivering fuel into the cylinder. Generally speaking, in the preferred embodiment fuel injection would start when the piston is about 19 degrees before bottom dead centre, but it will be appreciated that that would be variable to obtain the desired firing properties. As the exhaust port 316 is open a vacuum is created above the piston, which assists in drawing fuel in from the injector body 401. The downward movement is also forcing pressurised air into the upper part of the cylinder from the volume below the cylinder via the inlet ports 319, as described above with reference to Figure 3. That air is effectively supercharged, due to the pressure provided by the piston movement. The fuel from the injector body is mixed with the air which has entered the upper part of the cylinder from the inlet ports 319.

Meanwhile, the piston 300 in cylinder 105 is on its compression stroke, and the inlet and exhaust ports of that cylinder are closed. The compression movement applies pressure to the air/fuel mixture in the region above the piston 300 which drives some air/fuel mixture into the internal chamber 424 in the injector body 405. Due to the non-return valve 440 in the mixture inlet port 438 of injector body 405 preventing mixture from exiting via the mixture inlet port 438, as well as the non-return valve 430 preventing mixture from exiting via the fuel inlet port, the mixture is forced under relatively low pressure through the mixture outlet port 442 of the injector body 405 and pipe 446 into the mixture inlet port 438 of the injector body 401 associated with cylinder 101. The pressure in the air/fuel mixture being transferred is greater than the pressure in the upper part of the cylinder 101 at the time, which enables the transfer to take place. Some of the transferred mixture will remain in the pipe 446.

The piston 300 in cylinder 102 meanwhile, is on its power stroke, about 72 degrees behind the piston in cylinder 101. Due to the pressure in cylinder 102 being greater than in cylinder 101 and the configuration of the non-return valves in the ports, the mixture from cylinder 105 will be prevented from travelling beyond cylinder 101 to cylinder 102.

Referring now to Figure 6b, the piston in cylinder 101 is nearing the top of its compression stroke, the piston in cylinder 102 is earlier in its compression stroke, and the piston in cylinder 105 is on its power stroke just after combustion. The high pressure in cylinder 105 forces combusted mixture back up into injector body 405, and that is delivered to the neighbouring injector body 401 under combustion temperature and pressure, where it mixes with fuel. Due to the fuel outlet port 428 being less restrictive than the mixture outlet port, the majority of the mixture will travel to cylinder 101 rather than 102. Also, the time factor also prevents a large amount of the combusted mixture travelling to cylinder 102 at this stage of the process. The combusted mixture also forces any remaining residual mixture from the compression stroke in the pipe to the injector body associated with cylinder 101. Meanwhile, the upwards movement of the piston in cylinder 101 forces air/fuel mixture under relatively low pressure into cylinder 102.

Referring now to Figure 6c, cylinder 101 has just undergone combustion (which occurs just before top dead centre), and its piston 300 is on the power stroke. The piston in cylinder 102 meanwhile is nearing the top of its compression stroke, and the piston in cylinder 105 is further through its power stroke. Following combustion of the mixture in the cylinder 101, combusted mixture under combustion pressure and temperature is

delivered to the injector body 402 associated with cylinder 102, and will mix with the fuel in that injector 402 prior to combustion. Meanwhile, relatively low pressure air/fuel mixture will be delivered from injector body 402 to the injector body 403 associated with cylinder 103 due to the compression movement of the piston in cylinder 102.

Typical combustion pressures which may occur in an axial motor of this type are in the order of about 600psi to about 1000psi (about 4137 KPa to about 6895 KPa).

Meanwhile, there will be higher pressure in cylinder 105 than in cylinder 104 due to relatively recent combustion in cylinder 105, therefore no mixture will be delivered from cylinder 104 to cylinder 105 in the position shown in Figure 6c.

It will be appreciated that while only three cylinders are shown here, the procedure will continue in a sequential manner around the engine block. The same amount of fuel can be delivered to each injector body by the injectors, but the system will equalise the delivery of mixture and fuel as necessary around the engine.

It will be appreciated from the above description that a stratified combusted mixture under combustion pressure and temperature is transferred to a neighbouring injector body and mixed with a combustible mixture under compression pressure as that cylinder nears its firing position, to assist in atomising and distributing that combustible mixture in the cylinder.

It has also been found that during combustion in a cylinder, if piston rings are not used, then part of the combusted charge will travel down the sides of the piston. This assists in reducing the friction associated with piston movement, which is particularly useful if non-metallic pistons such as carbon pistons are to be used for example. The amount of combusted mixture being transferred to an adjacent cylinder is dependent on the combustion pressure, which is a product of the amount of fuel delivered into the cylinder prior to combustion. Therefore, the properties can be adjusted by altering the amount of fuel delivered to each cylinder by the respective injector and injector body. Further, the lengths of the pipes or tubes 446 can be adjusted to "tune" the properties of the fuel injection system. If longer pipes or tubes 446 are used there will be greater delay in delivery of the combusted mixture to the adjacent injector body, whereas if shorter pipes or tubes are used there will be less delay in delivery of the combusted mixture to the adjacent injector body.

By delivering combusted mixture under combustion temperature and pressure from one cylinder to a following cylinder, the combustion properties have been found to improve. The combusted mixture retards ignition in the following cylinder in the firing order. That enables higher compression ratios to be used with high density fuels such as A1 diesel hydrocarbon fuel, with reduced "knocking" or auto-ignition. Further, the elevated temperature and pressure of the combusted mixture picks up fuel in the adjacent injector body and atomises the fuel prior to its delivery into the cylinder, again improving combustion properties for that cylinder.

The above describes a preferred embodiment of the present invention, and modifications may be made thereto without departing from the scope of the invention. For example, while the motor is described as being a two-stroke axial motor, it could alternatively be a four-stroke axial motor. In that case, air/fuel mixture would be delivered from a cylinder to an adjacent cylinder under relatively low pressure during the compression stroke, and under higher pressure immediately following combustion.

Further, the motor may be an in-line, vee, or horizontally opposed ("boxer") configuration two- or four-stroke internal combustion motor, or a rotary engine.

It will be appreciated that the recirculation system need not be used in conjunction with an internal turbocharger, and it will work successfully with a normally aspirated engine. Further, the fuel injection system could be used in an axial motor having opposed pistons, such as that described in our PCT publication number WO 03/010417. It will be appreciated that if a fuel injection system is used with both banks of pistons in the opposed piston motor, the configuration of valves between the injectors in one bank will be the opposite to the other bank, so that overall the sequence of operation will be in the same direction for both banks.

Rather than providing the interconnection between injector bodies for transfer of combusted mixture, the transfer could be within the cylinder head of the motor. For example, the part of the cylinder head associated with the tops of each cylinder could have ports at or adjacent the tops of the cylinders. These ports could be interconnected via internal transfer means such as internal channels. In one embodiment, a pre-mix chamber is provided at the top of each cylinder, and the motor includes transfer means such as internal channels which are configured to deliver combusted mixture under combustion

temperature and pressure from the pre-mix chamber associated with a cylinder that has just fired to the pre-mix chamber associated with the next cylinder in the firing order. Each pre-mix chamber may have a mixture inlet port, a mixture outlet port, an aperture or port for receipt of fuel from a fuel injector, and a fluid path into the cylinder which preferably includes a nozzle or restriction to deliver mixture for combustion into the respective cylinder under pressure. The spark plug(s) associated with each cylinder are preferably present in the cylinder itself rather than in the pre-mix chamber, so that the combustion occurs in the cylinder and then forces combusted mixture back up into the pre-mix chamber and to the pre-mix chamber associated with the next cylinder in the firing order via the transfer means. The operation will generally be the same as described above.

However, it is preferred that the injector bodies and external transfer means are used, as they can more be easily dismantled for cleaning.

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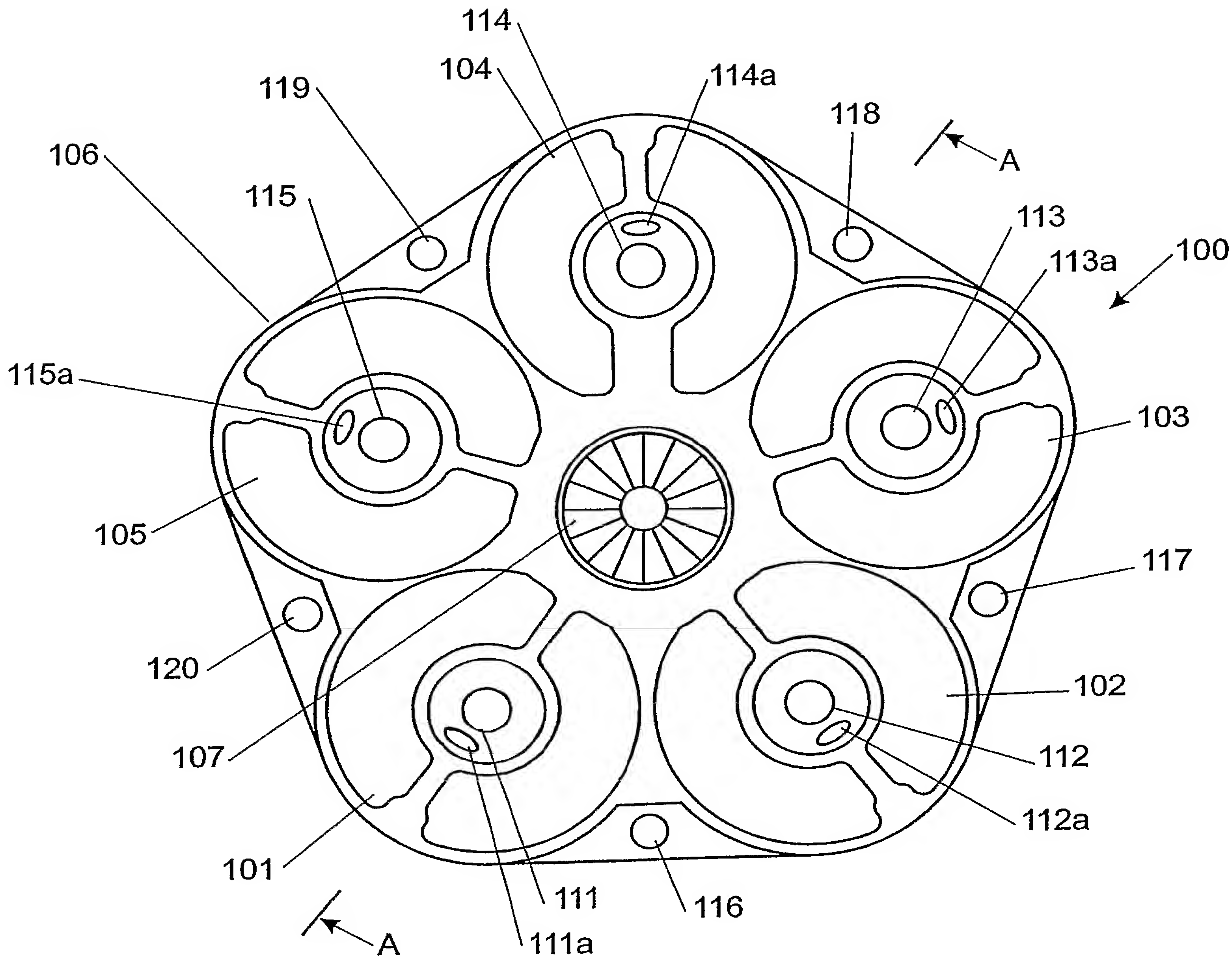
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FIGURE 1

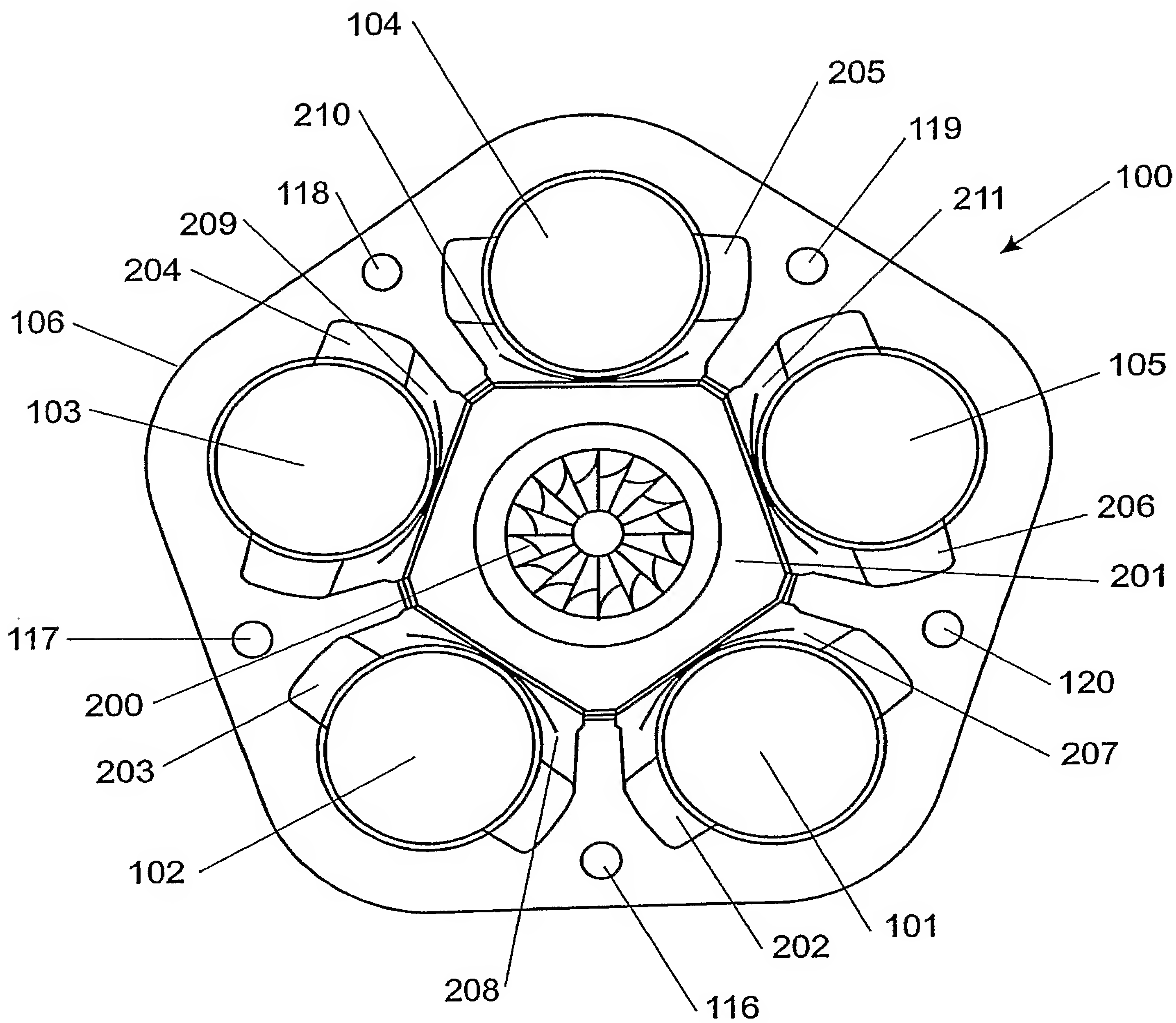
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FIGURE 2

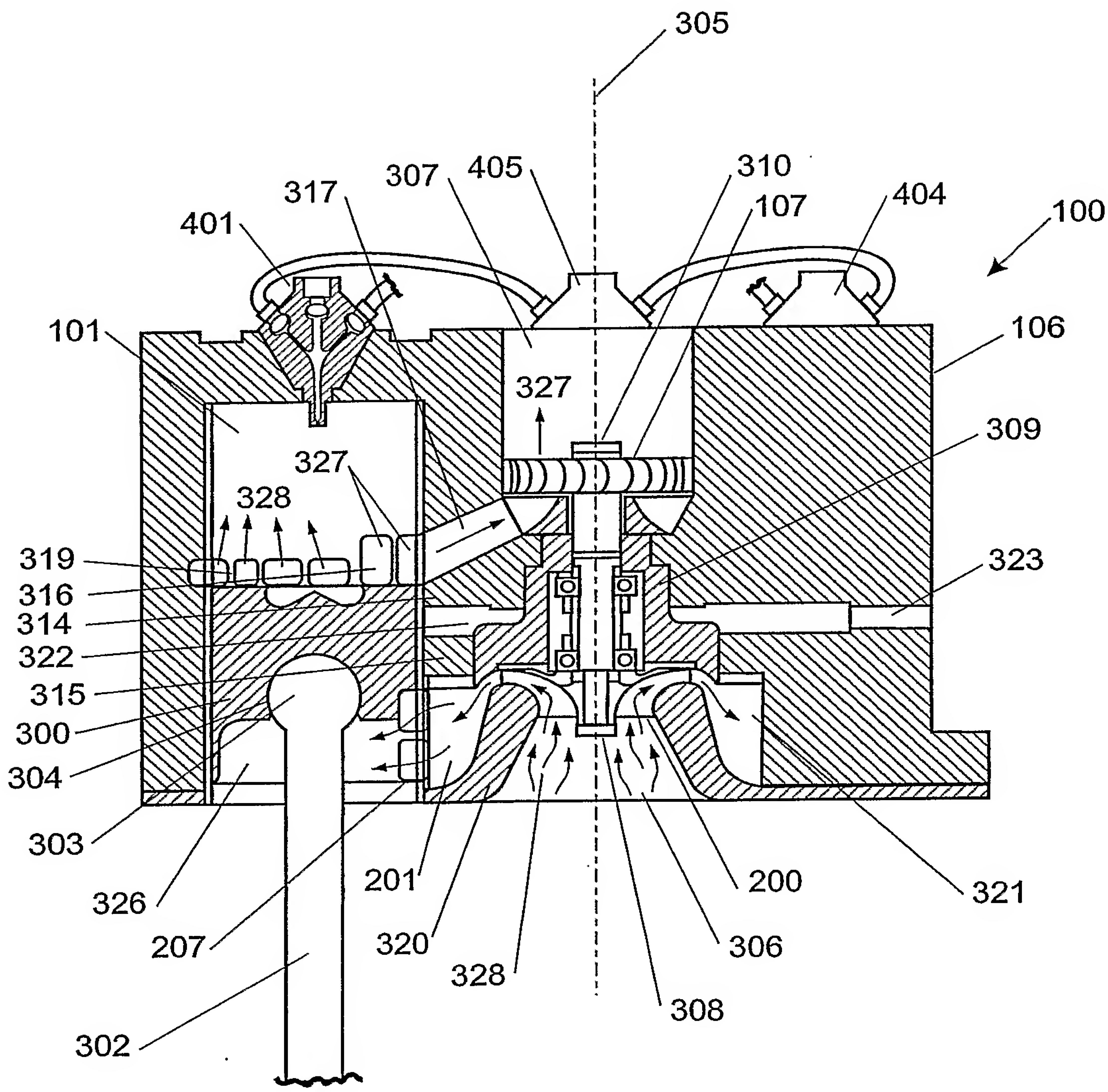
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FIGURE 3

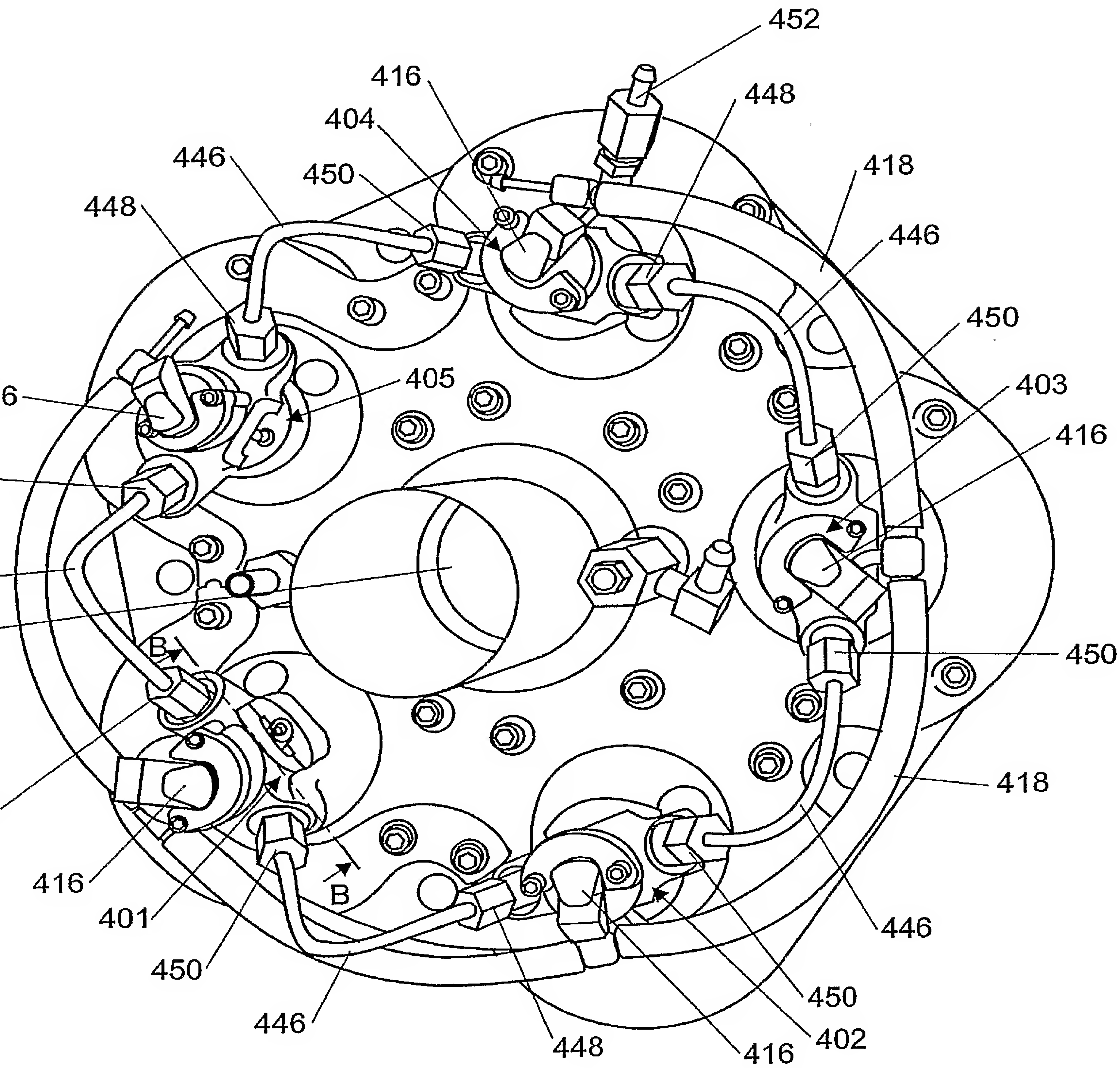
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FIGURE 4

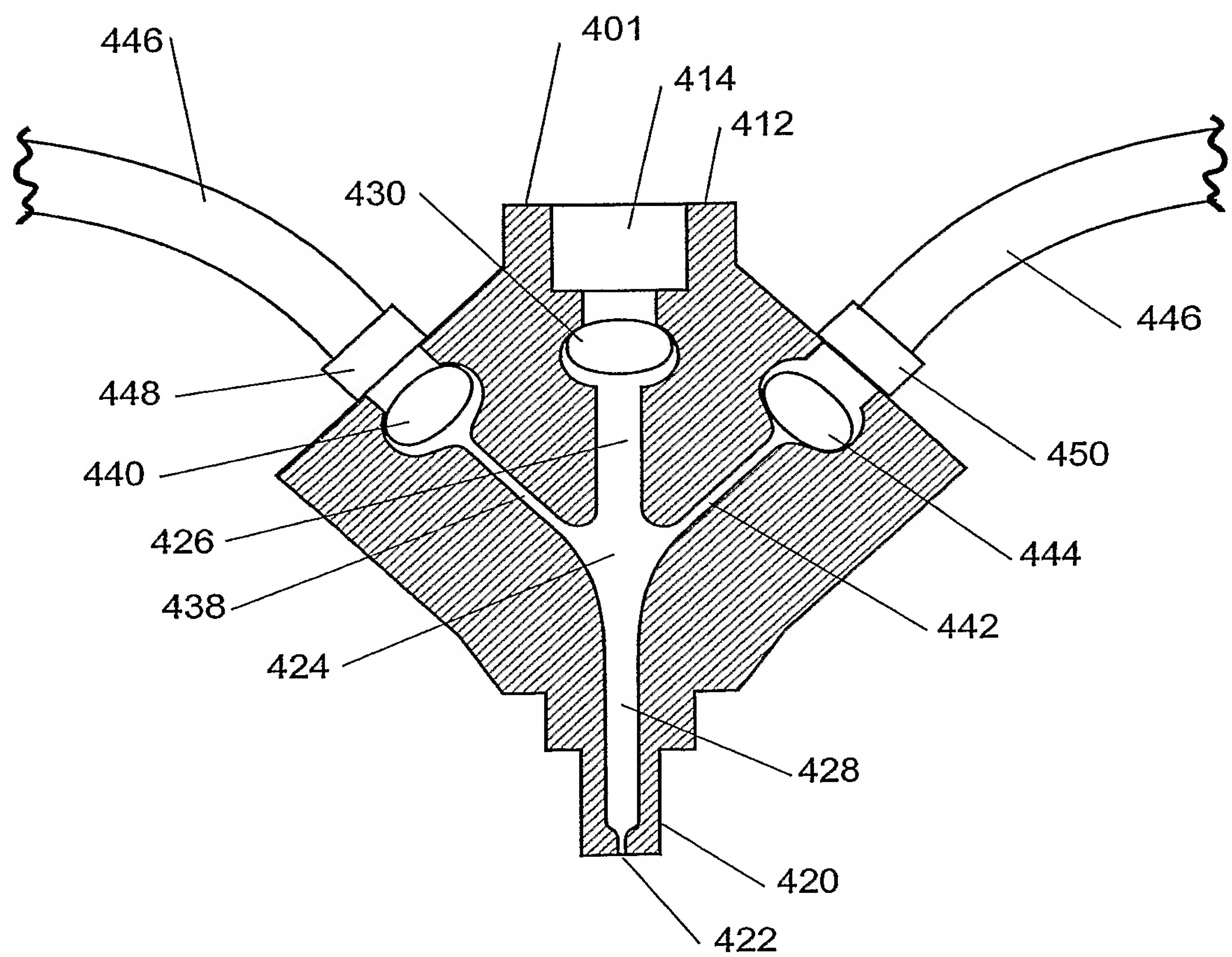
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FIGURE 5

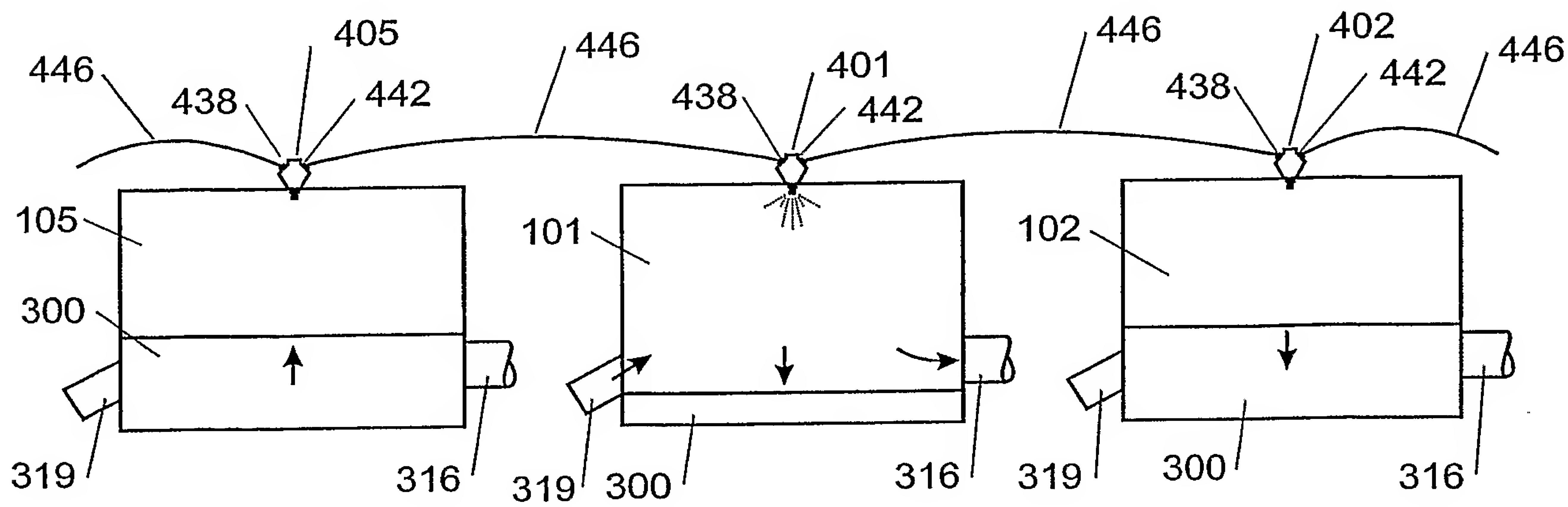

FIGURE 6a

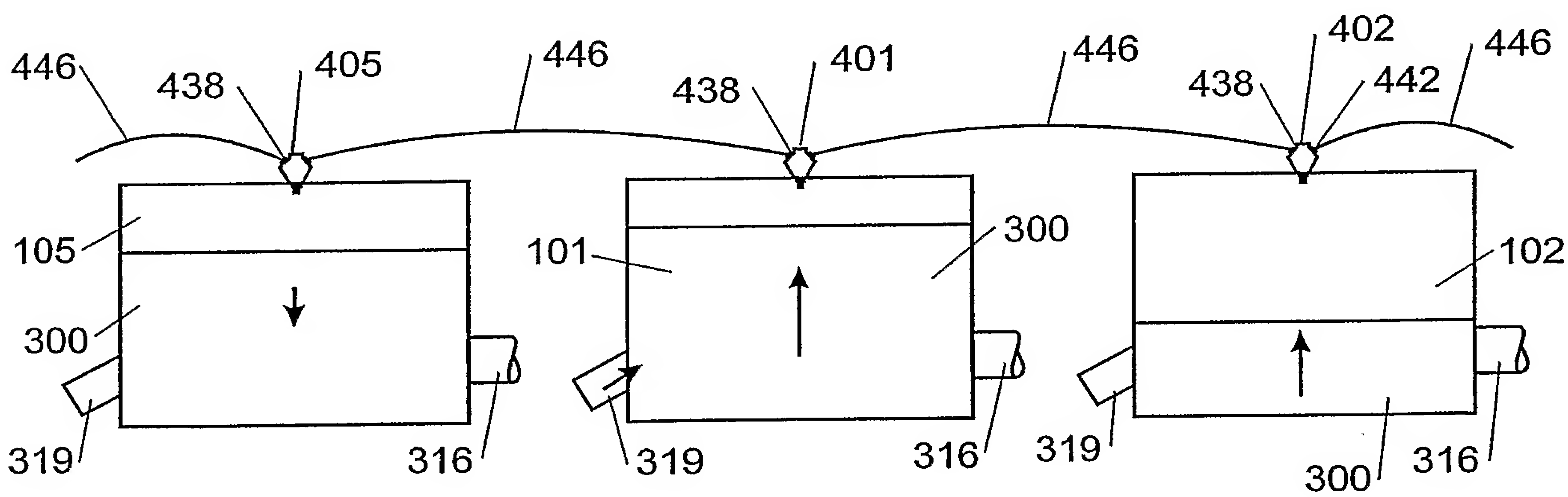

FIGURE 6b

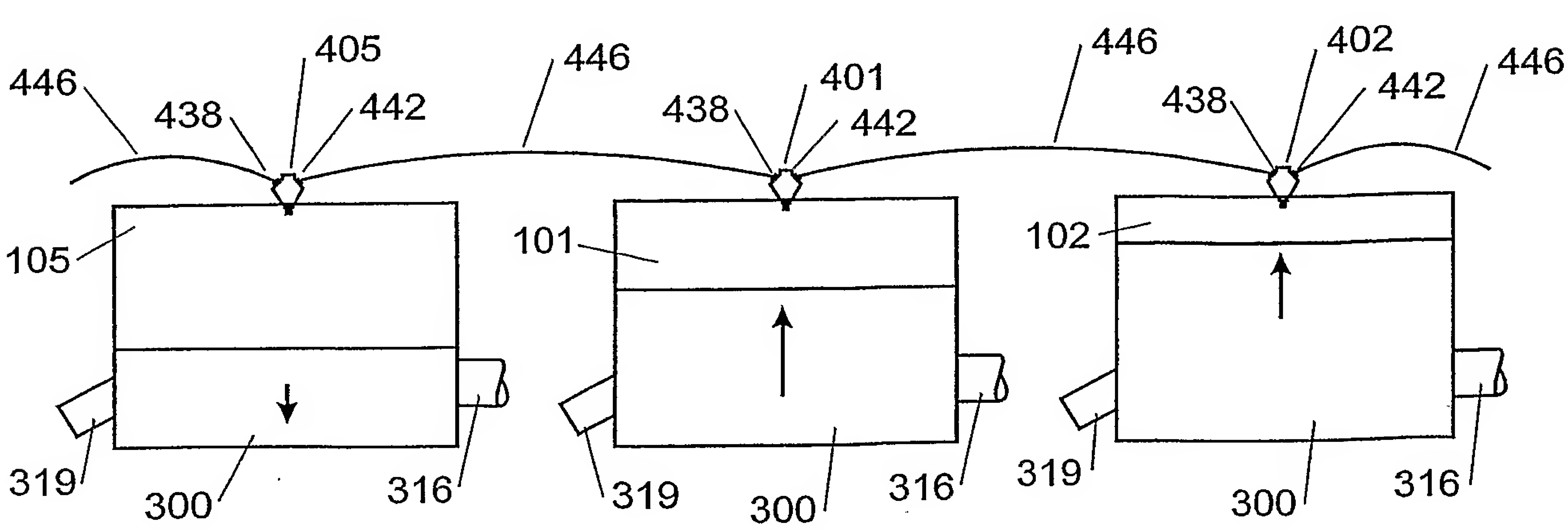

FIGURE 6c